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Selection of Solar Energy for Green Building Using Superiority and Inferiority Multi-criteria Ranking (SIR) Method

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ABSTRACT

Green energy is one of the key factors, driving down electricity bill and zero carbon emission generating electricity to green building. However, the climate change and environmental policies are accelerating people to use renewable energy instead of coal-fired (convention type) energy for green building that energy is not environmental friendly. Therefore, solar energy is one of the clean energy solving environmental impact and paying less in electricity fee. The method of solar energy is collecting sun from solar array and saves in battery from which provides necessary electricity to whole house with zero carbon emission. However, in the market a lot of solar arrays suppliers, the aims of this paper attempted to use superiority and inferiority multi-criteria ranking (SIR) method with 13 constraints establishing I-flows and S-flows matrices to evaluate four alternatives solar energies and determining which alternative is the best, providing power to sustainable building. Furthermore, SIR is well-known structured approach of multi-criteria decision support tools and gradually used in construction and building. The outcome of this paper significantly gives an indication to user selecting solar energy.

KEYWORDS

Solar energy, superiority and inferiority multi-criteria ranking (SIR) method, multi-criteria decision support (MCDS), green building, sustainable building

INTRODUCTION

In the past five years, the society, community, climate change issues and people focused on using decision support framework to determine solar energy for green building. A few researchers defined what is meaning of green building. For example, Jiang (2009) used simulation model like Energyplustm to assess the green building. Zheng (2009) used LCA and extenics theory for building energy conversation. Karajan et al. (2009) used fuzzy analytic hierarchy process to analyze, compare and select the renewable energy for building. But they still remained some problems using systematical study of evaluating solar energy, generating power to eco-building. In this research, superiority and inferiority multi-criteria ranking (SIR) methods would be used in systematically evaluation to determine which alternatives of solar energies are suitable for perspective users.

LITERATURE REVIEW

PROMETHEE is a well known multi-criteria decision support method which gives insight into the preference structure of a whole set of alternatives. The retrieved preference information is used to give the partial or complete preorder of the variable alternatives which makes PROMETHEE a well decision support tool if ranking of available alternatives is desired. The Promethean methods, as well as ELECTRE III are two of the most well-known and widely applied techniques belonging to the family of multiracial outranking methods. The basic principle of multi-criteria outranking methods is to work on the set of pair of action (instead of the set of action); in order to model only the explicit relations of preferences between two alternatives decision issues. The extension of PROMETHEE consists in more detailed investigation of the differences existing among the performances of the actions examined, achieved through the notion of ideal and anti-ideal alternative. The more accurate description of the reality leads to a relatively more reliable ranking of the available solutions and allows the exploitation of the results for construction of a cardinal scale, assigning to each action a numerical value in between 0 to 1. The quantities differentiation of the alternatives, thus achieved, gives another dimension of information, which is extremely useful for the decision making process (Kaklauskas et al.2007).

A superiority and inferiority ranking (SIR) uses two types of information, the superiority and the inferiority information. SIR derives two types of flows, the superiority flow and the inferiority flow, by which the set of alternatives are ranked partially or completely (Xu 2003).

Using a group multi-criteria decision making with fuzzy evaluation and incomplete information of criteria's weight and decision maker's weight, the preference functions within the PROMETHEE method are expanded embarking on the degree size between every pair of alternatives. Fuzzy programming optimization models are constructed to integrate the multi-criteria under a single-decision maker and the group decision makers' preferences and the whole attitude to risk. To allow for the determination of the range of values in which a judgment can oscillate, with an acceptable consistency, with affecting a "property" previously considered for the alternatives (the best, the ranking...) (Saguaro et al. 2003) . Although current researchers commonly used analytical hierarchy process (AHP), modify analytical process, fuzzy analytical hierarchy process (FAHP), artificial neural process (ANP) in construction and building industries. But those frameworks are seldom used in evaluating solar energy for sustainable building and a researcher is also no choices in preference of shape using those frameworks. Therefore, filling this gap, SIR is one of the good tools in multi-criteria decision support(MCDS) because it allows users to select preferences and shape generation , it makes the methods more flexible and expected outcome from SIR. According to the literature review, one of the finding is an aim of green buildings or sustainable buildings are the same because the outcome of those buildings are driving carbon emission, energy efficiency but they developed in different time frame. Another finding is that few researchers used SIR as MCDS framework comprehensively study solar energy for green building. Based on the finding, the proposed method was developed and discussed in methodology.

METHODOLOGY

This section discussed the SIR MCDS method and illustrated outwards. Let A_1, A_2, \dots, A_m be alternatives

and g_1, g_2, \dots, g_n be n cardinal criteria and let $g_j(A_i)$ be the criteria value (performance) of the i^{th} alternative A_i with respect to be j^{th} g_j , where $g_j(\cdot)$ is a real-valued function ($i = 1, 2, \dots, m; j = 1, 2, \dots, n$). These criterion values are forming a decision matrix D :

$$D = \begin{bmatrix} g_1(A_1) & g_j(A_1) & \dots & g_n(A_1) \\ g_1(A_2) & g_j(A_2) & \dots & g_n(A_2) \\ \vdots & \vdots & \ddots & \vdots \\ g_1(A_m) & g_j(A_m) & \dots & g_n(A_m) \end{bmatrix}$$

Compare the criteria values on each criteria, two alternatives A and A' and a criteria g , let $g(A)$ and $g(A')$ be the criteria values of A and A' with respect to g .

1. For ordinal criteria, if $g(A) > g(A')$, then one point is assigned to the superiority score of A and to the inferiority score of A' , respectively, on the criterion g . For cardinal criteria, the difference $d = g(A) - g(A')$ by using thresholds in the case or quasi-criteria.

$$P(A, A') = I(g(A) - g(A')) = f(d) \quad (1)$$

Where $f(d)$ is a non-decreasing function from \mathbb{R} which is real numbers to $[0, 1]$ such that $f(d) = 0$ for $d \leq 0$ (i.e. $g(A) \leq g(A')$). This function is called generalized criteria – see Figure 1. The parameters p and q in Figure 1 are preference and indifference thresholds, respectively. Gaussian criterion has been mostly selected by users for practical applications followed by the criterion with linear preference and indifferent area. In both criteria (like the criterion with linear preference), the intensity of preference changes gradually from 0 to 1 while in the other three criteria (true-criteria, quasi-criterion.

Generalized criteria		
Type 1 True criterion: $f(d) = \begin{cases} 1 & \text{if } d > 0 \\ 0 & \text{if } d \leq 0 \end{cases}$	Type 2 Quasi criterion: $f(d) = \begin{cases} 1 & \text{if } d > q \\ 0 & \text{if } d \leq q \end{cases}$	Type 3 Criterion with linear preference: $f(d) = \begin{cases} 1 & \text{if } d > p \\ d/p & \text{if } 0 < d \leq p \\ 0 & \text{if } d \leq 0 \end{cases}$
Type 4 Level criterion: $f(d) = \begin{cases} 1 & \text{if } d > p \\ 1/2 & \text{if } q < d \leq p \\ 0 & \text{if } d \leq q \end{cases}$	Type 5 criterion with linear preference and indifference area: $f(d) = \begin{cases} 1 & \text{if } d > p \\ (d - q)/(p - q) & \text{if } q < d \leq p \\ 0 & \text{if } d \leq q \end{cases}$	Type 6 Gaussian criterion: $f(d) = \begin{cases} 1 - \exp(-d^2/2\sigma^2) & \text{if } d > 0 \\ 0 & \text{if } d \leq 0 \end{cases}$

Figure 1 the Generalized Criteria (Rebai, 1991, 1994)

The above six types of generalized criterion are not exhaustive. Some other shapes can best meet the decision-makers preference attitudes (Rabai, 1991, 1994). The type 1 would select in this study. Let f_j be a generalized criterion adopted for the j^{th} criterion g_j ($j = 1, 2, n$). For each pair of alternatives A_i and A_k , let $P_i(A_i, A_k) = f_j(g_j(A_i), g_j(A_k))$ represents the intensity of preference or superiority respect to the j^{th} criterion. For each alternative A_i , we define its superiority index $S_j(A_i)$ and inferiority index $I_j(A_i)$ with respect to j^{th} criterion by the following formulas:

$$S_j(A_i) = \sum_{k=1}^m P_j(A_i, A_k) = \sum_{k=1}^m f_j(g_i(A_i) - g_j(A_k)). \quad (2)$$

$$I_j(A_i) = \sum_{k=1}^m P_j(A_j, A_i) \sum_{k=1}^m f_j(g_j(A_j) - g_i(A_i)) \quad (3)$$

Since $f_j(d) = 0$ for $d \leq 0$, eqt. 1 and eqts 2-3 can be rewrite:

$$S_j(A_i) = \sum \{f_j(f_j(g_j(A_i)) - g_j(A_k)) | g_j(A_i) > g_j(A_k)\} \quad (4)$$

If all f_j in eqt. 1 and eqt.4 are true criteria or quasi-criteria, then $S_j(A_i)$, I_j and (A_j) are exactly superiority score and the inferiority score respectively (Rebai, 1993, 1994 and Tam et al. 2004).

$$S = \begin{bmatrix} S_1(A_1) & S_2(A_1) & \dots & S_n(A_1) \\ S_1(A_2) & S_2(A_2) & \dots & S_n(A_2) \\ \vdots & \vdots & \ddots & \vdots \\ S_1(A_m) & S_2(A_m) & \dots & S_n(A_m) \end{bmatrix}$$

$$\text{Or } S = S_j(A_i)_{m \times n} \quad (5)$$

and the inferiority matrix (I-matrix):

$$I = \begin{bmatrix} I_1(A_1) & I_j(A_1) & \dots & I_n(A_1) \\ I_1(A_2) & I_j(A_2) & \dots & I_n(A_2) \\ \vdots & \vdots & \ddots & \vdots \\ I_1(A_m) & I_j(A_m) & \dots & I_n(A_m) \end{bmatrix}$$

$$I = I_j(A_i)_{m \times n} \quad (6)$$

The two matrices S and I include better information than the original decision matrix. The characteristics of superiority and inferiority Ranking is given by the generalized criteria in Figure 2. The superiority matrices S and I and the inferiority matrix I convey different information because they represent different types of comparison results. Note that the matrix $\Phi = S - I = \{S_j(A_i) - I_j(A_i)\}_{m \times n}$ is (up to a normal coefficient) the matrix Φ composed of the un-criterion flows $\Phi_j(A_i)$. It seemed that S -matrix and I -matrix contain “finer” (or more accurate) information than Φ because the latter contains only the “Net” information (Xu 2003). The of S -flows and I -flows matrices are shown in Figure 3 and Figure 2 is the analytic hierarchy process chart for selections 4 solar alternatives .

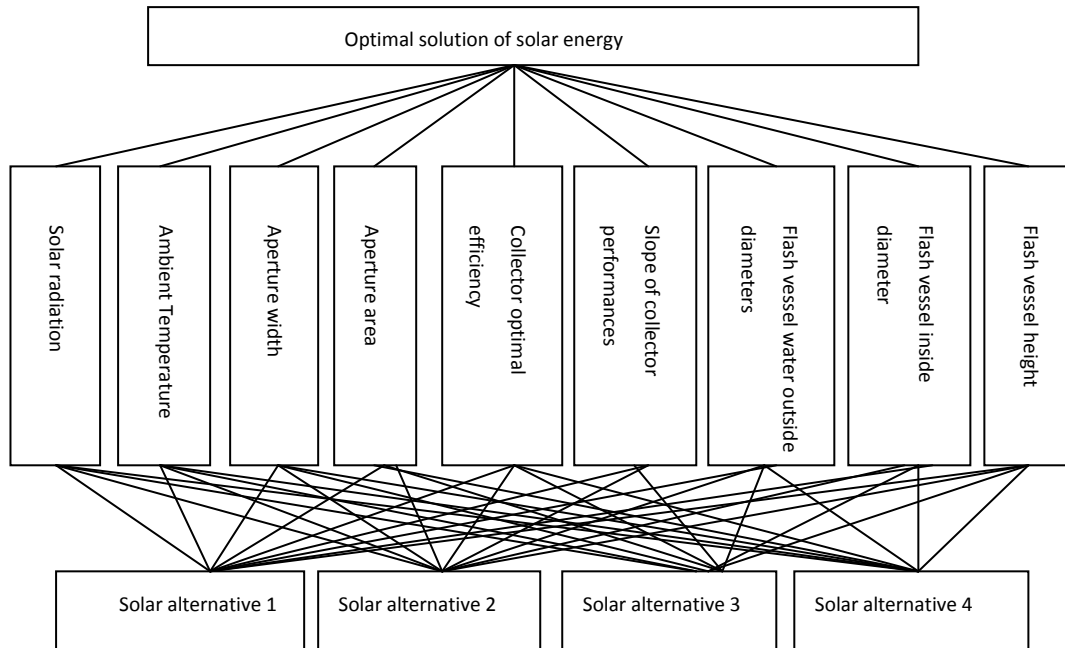


Figure 2 The Analytic Hierarchy Process Chart for Selection 4 Solar Alternatives

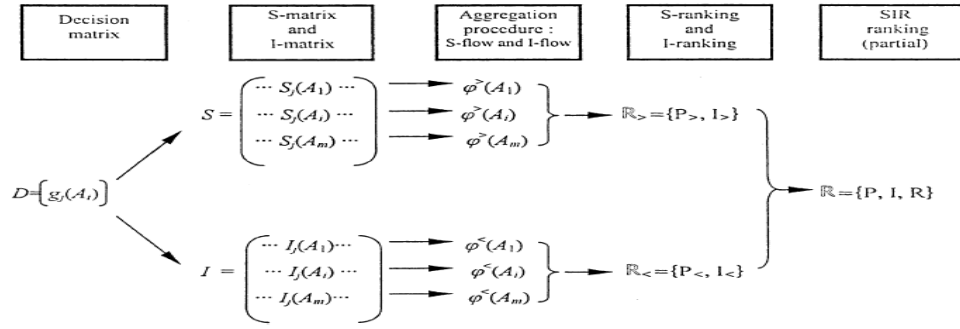


Figure 3 The Flow of S and I-matrices (Xu 2003)

Summary the Figure 3:

$$\varphi = S - I$$

S-flows:

$$\varphi^< = W * S$$

I-flows:

$$\varphi^> = W * I$$

(7)

Case Study

The 4 alternatives of solar energies would be studied in this research, using SIR method. In this study, the 13 technical data of each of alternatives would be evaluated and shown in Table 2. The technical data are solar radiation, ambient temperature, aperture area, collector optical efficiency, slope of collector performance graph, flash vessel water outside diameter, flash vessel inside diameter, flash vessel wall thickness, flash vessel height, UV values of the pipes, pump body area, insulation conductivity. Because some data like solar radiation and ambient temperatures are a set of range data, therefore, we took their average values. In this comparison, all alternatives are used in same conditions and would not be affected by the geographical problems such radiation and ambient. There are six steps to use SIR:

- Step 1: Construct the Comparison Tables against other alternatives
- Step 2: Transform the Matrix
- Step 3: Calculate the Weighting
- Step 4: Calculate the S-matrix
- Step 5: Calculate the I-matrix
- Step 6: Aggregation

Adopting Kaklauskas et al.(2007), Tam et al.(2004) and Xu(2003) methods, this study aims to collect current solar energy technical data China market shown as and Tables 2-3 respectively. Due to calculation the weighting of 4 alternatives by AHP shown as Table 4, some technical data in the Table 2 would be taken the average values instead of the range values, especially solar radiation and ambient

temperature column and shown into Table 3. For example, the range values 100 ± 5 are values within 95 to 105, but in this research, it only counted 100 due to calculation purposes. However, in Table 2, the notation of g_1 , g_2 , g_3 and g_4 are:

g_1 = Solar Energy alternative 1

g_2 = Solar Energy alternative 2

g_3 = Solar Energy alternative 3

g_4 = Solar Energy alternative 4

Step 1: Construct

Table 2 Solar Thermal Technical Characteristics.

Parameter	g_1	g_2	g_3	g_4
Solar radiation($w m^{-2}$)	550	600-800	550-810	600-800
Ambient Temperature	32	33 to 39	33-45	33-45
Aperture width(m)	1.46	3	3	3
Aperture area(m)	3.5	6	6.1	6.1
Collector optical efficiency	0.655	75	76	74
Slope of collector performances graph($w m^{-2} K^{-1}$)	0.387	0.41	0.41	0.41
Flash vessel water outside diameter(mm)	0.7	0.7	0.41	0.42
Flash vessel inside diameter(mm)	105	105	105	105
Flash vessel wall thickness(mm)	65	65	65	65
Flash vessel height(m)	2	3	3	3
UV value of the pipes($W K^{-1}$)	0.6	0.6	0.6	0.6
Pump body area(m^2)	0.93	1.2	1.2	1.2
Insulation conductivity($W m^{-1} K^{-1}$)	0.35	0.33	0.33	0.33

Table 3 Re-Construct the Solar Thermal Characteristics

Parameter	g_1	g_2	g_3	g_4
Solar radiation($w m^{-2}$)	550	700	680	700
Ambient Temperature	32	36	39	39
Aperture width(m)	1.46	3	3	3
Aperture area(m)	3.5	6	6.1	6.1
Collector optical efficiency	.65.5	75	76	74
Slope of collector performances graph($w m^{-2} K^{-1}$)	0.387	0.41	0.41	0.41
Flash vessel water outside diameter(mm)	0.7	0.7	0.41	0.42
Flash vessel inside diameter(mm)	105	105	105	105
Flash vessel wall thickness(mm)	65	65	65	65
Flash vessel height(m)	2	3	3	3
UV value of the pipes($W K^{-1}$)	0.6	0.6	0.6	0.6
Pump body area(m^2)	0.93	1.2	1.2	1.2
Insulation conductivity($W m^{-1} K^{-1}$)	0.35	0.33	0.33	0.33

Step 2: SIR Process

Table 4 SIR Process(es) for 4 Alternatives Selection

Criteria g_i	g_1	g_2	g_3	g_4
Type of criteria	6	6	6	5
Weight w_j , $\sum=1$	0.217515	0.24876	0.303679	0.23005
Preference threshold p	1.5	N/A	3	2
Indifference threshold q	0.5	N/A	0.1	1
Non decreasing/non-increasing:1/0	1	1	1	1

Step 3 Calculated S-matrix

From eqts. 3-4 and eqt.6:

$$S = \begin{bmatrix} -430 & 3 & -12.46 & -605.1 & 0.445 & -0.069 & 0.58 & 0 & 0 & -3 & 0 & -0.81 & 0.06 \\ 705 & 20 & 1.54 & -1187.6 & 0.625 & 0.023 & 0.58 & 0 & 0 & -8 & 0 & 0.27 & -0.02 \\ 772 & 10 & 1.54 & 1787.4 & -0.535 & 0.023 & -0.58 & 0 & 0 & -0.509091 & 0 & -3.06 & -0.02 \\ 170 & 10 & 1.54 & -592.2 & -0.535 & 0.023 & -0.58 & 0 & 0 & -2.09091 & 0 & 0.27 & -0.02 \end{bmatrix} \quad (8)$$

Step 4: Calculated I-matrix

From eqts 3-4 and eqt.7:

$$I = \begin{bmatrix} 170 & 18 & 4.62 & 602.6 & -0.445 & 0.069 & -0.58 & 0 & 0 & 3 & 0 & 0.81 & -0.06 \\ -190 & 2 & -1.54 & 592.6 & -0.625 & -0.023 & -0.58 & 0 & 0 & -1 & 0 & -0.27 & 0.02 \\ -1210 & -10 & -1.54 & -1787.4 & 0.535 & -0.023 & 0.58 & 0 & 0 & -1 & 0 & -0.27 & 0.02 \\ -190 & -10 & -1.54 & 592.2 & 0.535 & -0.023 & 0.58 & 0 & 0 & -1 & 0 & -0.27 & 0.02 \end{bmatrix} \quad (9)$$

Step 5: Aggregation

From eqts.8-9, eqt.5 and Table 4:

Calculated S-flows:

From Table 1 and eqt.8:

$$\varphi^< = W * S$$

$$W = [0.217513 \quad 0.24876 \quad 0.303679 \quad 0.23005]$$

$$\varphi^< = W * I$$

$$W = [0.217513 \quad 0.24876 \quad 0.303679 \quad 0.23005]$$

$$I = \begin{bmatrix} 170 & 18 & 4.62 & 602.6 & -0.445 & 0.069 & -0.58 & 0 & 0 & 3 & 0 & 0.81 & -0.06 \\ -190 & 2 & -1.54 & 592.6 & -0.625 & -0.023 & -0.58 & 0 & 0 & -1 & 0 & -0.27 & 0.02 \\ -1210 & -10 & -1.54 & -1787.4 & 0.535 & -0.023 & 0.58 & 0 & 0 & -1 & 0 & -0.27 & 0.02 \\ -190 & -10 & -1.54 & 592.2 & 0.535 & -0.023 & 0.58 & 0 & 0 & -1 & 0 & -0.27 & 0.02 \end{bmatrix}$$

$$\varphi^< = W * S$$

$$W = [0.217513 \quad 0.24876 \quad 0.303679 \quad 0.23005]$$

$$S = \begin{bmatrix} -430 & 3 & -12.46 & -605.1 & 0.445 & -0.069 & 0.58 & 0 & 0 & -3 & 0 & -0.81 & 0.06 \\ 705 & 20 & 1.54 & -1187.6 & 0.625 & 0.023 & 0.58 & 0 & 0 & -8 & 0 & 0.27 & -0.02 \\ 772 & 10 & 1.54 & 1787.4 & -0.535 & 0.023 & -0.58 & 0 & 0 & -0.509091 & 0 & -3.06 & -0.02 \\ 170 & 10 & 1.54 & -592.2 & -0.535 & 0.023 & -0.58 & 0 & 0 & -2.09091 & 0 & 0.27 & -0.02 \end{bmatrix}$$

Step 6 Aggregation

Based on steps 3, 4, 6 and eqts 8-9, the aggregation is as shown in Table 5. The calculation of the S-flows and I-flows are in Table 5, which is toward S-flows and listed:

Table 5 S-flows and I-flows

S-Flows($\varphi^>$)	I-flows($\varphi^<$)
356.0.989	-421.6883
10.9850	-0.9225
-1.5036	-0.2365
-21.6719	127.4791
-0.0327	0.0327
0.0030	-0.0030
0	0
0	0
-0.327862	-3.2862
0	0
-0.1396	-0.0354
-0.0026	-0.1170

LIMITATION AND DISCUSSION

This research did not consider the solar grid connection to public is one of selection criteria in SIR, but only evaluation which options of solar energies system are the best. This study did not consider, investment, installation and operation costing as for constraints of data collection of four alternatives but only considers technical side of each alternative to use SIR to determine which one is the best. Indeed, in this research only considered the type 5 or 6 generation criteria shapes for selection criteria because it is one of the popular shapes. A variety of shapes combination would have different outcome results.

CONCLUSIONS

This study focused in using SIR framework to evaluate 4 alternatives with 13 constraints to determine which options are the best to drive down the electricity bill and less environmental impact to the society. Each constraint was carefully considered their purposes for data collection and weighed by SIR. In this study, according to previous evaluation by SIR, the alternative 3 is the best. But different

arrangement matrices would be affected the outcome results of the S-flows and I-flows. For examples, 3 * 4 matrix or 4 * 3 matrix. Furthermore, others constraints such as solar array, location, slope, sunshine hours, and vessel tanks were also affected solar energies performances and I-flows and S-flows results, especially slope of solar array and location. At last, one of difficult task is data collection of each constraint to establish I-flows and S-flows matrices. In the future research work, fuzzy database with Extensible Markup Languages (XML) will be attempted to perform this goal. Rather, the possibility distribution theory with XML is also the alternative methods solving the data collection problems and provides sufficient data to SIR to carry calculation that saving time.

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